

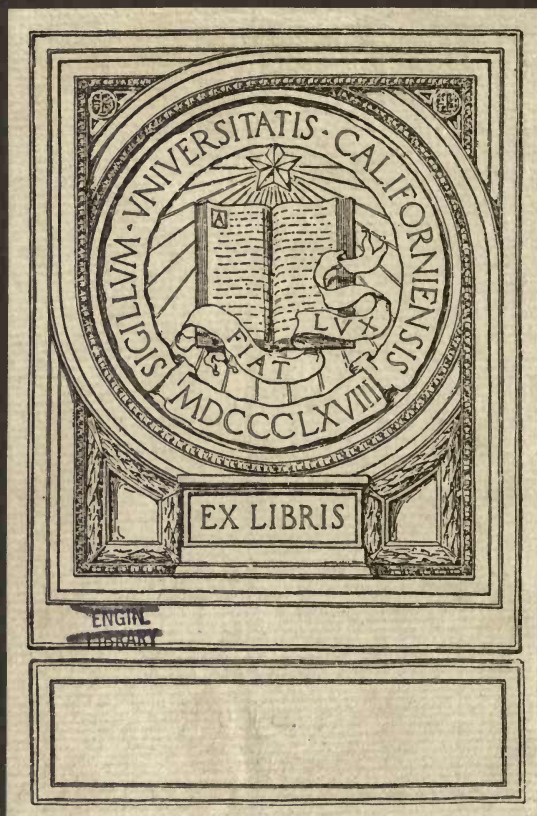
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THE MORTAR-MAKING QUALITIES  
OF ILLINOIS SANDS

BY  
C. C. WILEY



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# UNIVERSITY OF ILLINOIS ENGINEERING EXPERIMENT STATION

BULLETIN No. 70

DECEMBER, 1913

## THE MORTAR-MAKING QUALITIES OF ILLINOIS SANDS

By C. C. Wiley, Associate in Civil Engineering

CONTENTS		Page
I.	Introduction .....	3
1.	Preliminary .....	3
2.	Purpose .....	4
3.	Acknowledgment .....	4
II.	Description of Tests.....	5
4.	Preparation of Samples.....	5
5.	Tensile Strength .....	5
6.	Cleanness .....	8
7.	Sieve Analysis .....	8
8.	Specific Gravity .....	10
9.	Voids .....	11
10.	Weight .....	12
11.	Mineralogical Composition and Sharpness.....	12
III.	Description of Sands .....	13
IV.	Discussion of Tests.....	27
12.	Mineralogical Composition .....	27
13.	Specific Gravity .....	28
14.	Sharpness .....	28
15.	Voids .....	29
16.	Size and Gradation of Grains.....	29
17.	Cleanness .....	31
18.	Tensile Strength .....	32
19.	Crushed Stone Screenings.....	34
20.	Proportioning .....	34
V.	Specifications for Sand .....	35
21.	Need for Definite Specifications.....	35
22.	Definition of Sand and Screenings .....	35
23.	Suggested Classification of Sands.....	36

	Page
24. Suggested Specifications for Sand.....	36
Specifications for No. 1 Sand.....	36
Specifications for No. 2 Sand.....	37
Specifications for No. 3 Sand.....	37
Specifications for Plastering Sand .....	37
Specifications for Grout Sand .....	38

### LIST OF TABLES

1. Tensile Strength 1:3 Mortar.....	6
2. Sieve Analysis .....	9
3. Specific Gravity, Voids, and Weight.....	10
4. Summary of Data .....	12

### FIGURES

1. Sieve Analysis Curves for Samples 1 to 8.....	18
2. Sieve Analysis Curves for Samples 9 to 16.....	19
3. Sieve Analysis Curves for Samples 17 to 24.....	20
4. Sieve Analysis Curves for Samples 25 to 32.....	21
5. Strength of Briquettes Made of Illinois Sands in Terms of the Strength of Standard Ottawa Mortar.....	33
6. Photographs of Samples No. 0 to 5.....	38
7. Photographs of Samples No. 6 to 11.....	38
8. Photographs of Samples No. 12 to 17.....	38
9. Photographs of Samples No. 18 to 23.....	38
10. Photographs of Samples No. 24 to 29.....	38
11. Photographs of Samples No. 30 to 32.....	38



## THE MORTAR-MAKING QUALITIES OF ILLINOIS SANDS.

### I. INTRODUCTION.

1. *Preliminary.*—Mortar is defined by the American Railway Engineering Association\* as “a mixture of fine aggregate, cement or lime, and water used to bind together the materials in concrete, stone or brick masonry, or to form a covering for the same”. The fine aggregate is further defined as “sand or crushed stone screenings”.

It would be very difficult to obtain an accurate estimate of the total amount of sand annually used in Illinois for building purposes, but it is doubtless considerably in excess of a million cubic yards.† This enormous quantity of sand is obtained from many deposits, which differ widely in geological conditions, and consequently the sands from different localities may differ greatly in character. It is, therefore, only reasonable to expect that the mortar made of these different sands may vary greatly in quality. Since the mortar is an important element in masonry construction, it would be expected that the sand would be carefully selected and tested in order that the mortar may be of the highest quality, and yet this is not usually done. As a rule, the brick or other materials are selected with reasonable care and the cement is carefully inspected and tested, while the sand usually receives little more than a brief “clean and sharp” in the specifications and a casual glance at the sand pile by way of inspection. As a result, inferior sands producing mortars deficient in both durability and strength are often used when excellent sands are almost as easily obtainable. The existence of such a condition can be attributed only to a failure to realize that sands differ greatly in quality and that the quality of the mortar depends largely on the character of the sand. On some important work elaborate tests of the sand have been made, and the results of these tests, together with those from tests on concrete aggregates, have attracted considerable attention, which has resulted in an increased appreciation of the value of good sands. There is a growing demand for more information concerning the general characteristics of sands, as well as for reliable data on the mortar-making qualities of typical sands.

\*Bulletin No. 180, p. 173-174.

†Circular No. 5 of the Illinois State Geological Survey gives the total amount of building sand produced in the State in 1908 as 1,082,507 cubic yards. Since this report fails to take into account sand used by private parties from private deposits, and since considerable quantities are shipped in from adjoining States, probably balancing that shipped out, it is safe to say that these figures are conservative.

2. *Purpose.*—In view of the conditions mentioned above, a series of tests to determine the mortar-making qualities of a number of representative sands in common use in the cities of Illinois was undertaken with the belief that such data would be of assistance to the engineers and builders of the State in making an intelligent and economical use of the available sands. It is not the function of this bulletin to give a treatise on the use of sands, and therefore only such theoretical or general points are discussed as are essential to the explanation of the tests or to the interpretation of the results. The data obtained from these tests are directly applicable to mortar for stone or brick masonry; and in all probability apply equally well to concrete, since concrete is essentially a mass of rock fragments bound together by mortar, and in no other kind of masonry is the ultimate strength as dependent on the strength of the mortar as in concrete.

3. *Acknowledgment.*—The tests were made in the Cement Laboratory of the Department of Civil Engineering of the University of Illinois under the immediate supervision of the writer. Acknowledgment is here made of the assistance in making the tests of Messrs. J. W. McManus, E. B. Adams, F. T. Heyle, G. A. Barth, and W. Koestner, senior civil engineering students; and also of the assistance of Mr. B. L. Bowling, Assistant in Charge of the Laboratory, both in making the tests and in comparing, arranging, and checking the data.

The work was made possible in a large measure by the courtesy of a number of city engineers of the State in furnishing samples of sand; and acknowledgment is here made of their co-operation. The following list gives the cities whose engineers furnished samples of sand for these tests, together with the reference numbers used to designate the various samples. In several instances the locality from which the sand was obtained is not the same as the city furnishing the sample, and the name given any particular sand in the following tables and discussion is that of the location of the deposit from which the sample was taken.

Aurora .....	17	Galesburg .....	13
Beardstown .....	27	Jacksonville .....	26
Bloomington .....	7	Joliet .....	18
Cairo .....	25	Moline .....	19
Champaign .....	12	Mt. Carmel .....	28
Chicago .....	1, 2, 3, 4	Paris .....	23
Decatur .....	14	Rockford .....	8
East St. Louis .....	21	Springfield .....	9, 10, 11
Elgin .....	5, 6	Taylorville .....	24
Freeport .....	15, 16	Waukegan .....	22

Samples No. 20, 29, 30, 31, and 32 were collected personally by the students mentioned above.



## II. DESCRIPTION OF TESTS.

4. *Preparation of Samples.*—The samples of sand were shipped to the laboratory in bags or in tight, paper-lined boxes. As soon as a sample was received it was given a "sample number" for identification. It was then screened to pass a wire sieve having square openings of 0.20 in., thoroughly dried over a steam coil, and then stored in wooden lockers in a room maintained at about 70° F. It will be noted that a maximum size of grain of 0.20 in. was used throughout these tests. This size was adopted at the beginning of the series of tests which was before the national engineering societies generally adopted 0.25 in. as the maximum size\*; and in the later tests it was thought unwise to make a change as it was impracticable to repeat some of the earlier tests. Fortunately the difference arising from using 0.20 instead of 0.25 is very small, since none of the sands contained an appreciable amount of material larger than 0.20 in.

Each sand was tested for cleanness, gradation of size of grains (sieve analysis), specific gravity, voids, and weight. The approximate mineralogical composition and comparative sharpness were also determined. Tests for tensile strength were made on mortars made of each of the sands. In making all of these tests especial care was taken to eliminate the personal factor from the results.

5. *Tensile Strength.*—Tensile tests were made on mortars composed of portland cement and the various sands mixed in the proportions of 1:3 by weight. The cement used was a standard brand bought on the open market. Two bags of cement purchased at the same time were used. Tests of the neat cement from each bag gave the same results, within the limits of observation, as follows: Percentage passing the No. 100 and 200 sieves, 96 and 80 respectively; percentage of water for normal plasticity 21.0; tensile strength 642, 772, and 785 lb. per sq. in. at seven, twenty-eight, and ninety days, respectively. The sand mortars were mixed with 9 per cent of water, corresponding to the 21 per cent above, as required by the Specifications for the Uniform Tests of Cements with standard sand. This amount of water was sufficient for the clean, hard sands but with dirty or soft sands the mortars were quite dry. However, as the utmost care was taken in molding the briquettes, it is not believed that this has any considerable effect on the results, especially at the ages of twenty-eight and ninety days. The mortars were mixed in batches sufficient for six briquettes. Eighteen briquettes were made from each

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\*Recommended to the societies in 1909 by their joint committee and adopted by the societies in 1910 and 1911.

TABLE 1.—TENSILE STRENGTH OF 1:3 MORTARS.

No.	Sand. Name.	Age, Days	Tensile Strength—Pounds per Sq. In.						
			Individual Briquettes.						
00	Neat cement	7	615	645	640	690	620	...	642
		28	780	730	770	760	720	...	772
		90	755	820	785	780	...	...	785
0	Ottawa standard, 20-80	7	220	200	220	280	230	...	225
		28	310	300	315	340	315	295	318
		90	375	365	375	370	360	365	368
1	Chicago K. I. Co.	7	115	110	108	113	108	...	111
		28	205	195	190	200	165	195	192
		90	210	210	210	190	205	...	205
2	Chicago Z. R. Co.	7	150	175	175	145	150	...	159
		28	800	260	275	290	250	270	274
		90	315	310	330	290	...	...	311
3	Chicago K. I. Co.	7	200	220	205	170	180	...	195
		28	265	295	260	270	305	290	281
		90	320	310	320	305	315	...	314
4	Joliet limestone screenings	7	220	240	200	210	220	...	213
		28	295	335	365	350	330	...	335
		90	450	530	505	460	...	...	485
5	Elgin, Ham- mond pit	7	245	270	240	220	250	...	245
		28	330	375	395	425	410	380	394
		90	465	455	450	445	490	480	464
6	Elgin, Stimpson pit	7	190	180	210	225	210	200	203
		28	340	340	360	350	390	...	356
		90	415	420	405	400	...	...	410
7	Bloomington	7	225	230	225	235	210	225	225
		28	225	265	250	240	235	260	246
		90	295	305	275	285	270	...	286
8	Rockford	7	250	240	260	230	245	265	248
		28	335	345	350	335	330	340	339
		90	385	380	410	360	395	385	386
9	Lincoln	7	235	220	230	210	200	205	217
		28	285	270	275	285	275	290	279
		90	310	310	290	300	300	305	303
10	Alton	7	185	180	175	185	150	175	175
		28	245	230	250	255	220	260	243
		90	275	270	260	270	270	270	269
11	Alton	7	180	195	210	195	190	...	194
		28	245	235	250	245	240	...	243
		90	270	285	295	280	270	280	280
12	Covington, Ind	7	205	185	200	200	205	195	198
		28	265	230	250	230	235	245	267
		90	315	315	310	305	315	300	310
13	Gladstone	7	190	180	180	170	170	180	179
		28	230	220	205	210	225	220	218
		90	250	235	240	230	240	250	241
14	Decatur	7	270	310	285	285	305	265	287
		28	380	375	355	355	360	...	365
		90	425	435	420	430	430	...	428
15	Freeport	7	245	205	200	220	190	225	214
		28	275	285	270	260	265	265	270
		90	335	330	320	315	310	295	317



TABLE 1.—TENSILE STRENGTH OF 1:3 MORTARS—Continued.

Sand.		Age, Days	Tensile Strength—Pounds per Sq. In.						
No.	Name.		Individual Briquettes.						
16	Freeport Sand- stone screen- ings	7	180	180	195	220	170	195	190
		28	220	250	240	210	250	235	234
		90	235	260	270	270	300	280	269
17	Aurora	7	270	290	260	270	270	...	272
		28	390	415	400	435	410	...	410
		90	470	460	450	450	440	...	454
18	Joliet	7	120	130	98	100	100	100	108
		28	100	105	125	115	140	160	124
		90	145	170	155	150	150	175	159
18	Joliet (washed)	...	...	...	...	...	...	...	...
		28	150	170	190	175	185	185	176
		...	...	...	...	...	...	...	...
19	Moline	7	160	180	175	170	160	180	171
		28	250	225	235	245	...	...	239
		90	275	260	260	245	240	265	257
20	Urbana	7	190	185	190	200	200	195	193
		28	240	240	230	220	245	265	240
		90	365	320	315	310	340	330	330
21	E. St. Louis	7	170	185	170	160	170	175	179
		28	195	210	205	190	210	230	207
		90	285	275	230	245	245	265	258
22	Waukegan	7	140	145	160	175	155	140	158
		28	235	230	225	225	230	220	223
		90	300	270	280	310	305	310	296
23	Paris	7	125	130	120	130	120	115	123
		28	200	200	200	205	190	190	193
		90	260	245	235	265	245	255	259
24	Taylorville	7	110	100	100	115	130	135	113
		28	140	155	150	155	185	160	149
		90	210	220	195	220	200	220	211
25	Cairo	7	155	155	140	155	175	140	153
		28	260	210	235	220	245	240	234
		90	300	295	300	325	280	285	298
26	Hannibal,	7	160	150	150	175	175	180	165
		28	220	200	205	225	180	220	203
		90	290	270	290	275	275	275	279
27	Beardstown	7	95	80	90	90	90	70	86
		28	115	105	100	105	115	100	107
		90	145	130	150	135	135	145	140
28	Mt. Carmel	7	100	100	85	100	100	105	99
		28	140	135	130	140	125	140	135
		90	185	175	175	165	160	160	170
29	La Salle	7	130	120	130	110	100	110	117
		28	200	180	175	190	200	170	186
		90	175	200	185	190	210	200	194
30	Peoria	7	195	170	180	185	170	170	178
		28	200	205	200	205	210	210	205
		90	235	260	265	260	280	270	262
31	Peoria	7	165	140	175	135	150	135	167
		28	210	220	230	200	235	235	221
		90	315	320	295	285	320	300	306
32	Peoria	7	120	110	105	105	115	125	114
		28	155	155	145	145	160	160	153
		90	185	170	190	180	165	180	173

sand. Two briquettes from each batch, or six in all from each sand, were tested at the ages of seven, twenty-eight, and ninety days. The entire series of briquettes were molded as nearly at the same time as practicable, and all other precautions were taken to maintain uniform conditions throughout the mixing and molding. After being molded the briquettes were kept in moist air for about twenty-four hours and then stored in water maintained at about 70° F. in tanks so arranged that the water was gradually changed. Upon reaching the required age the briquettes were removed from the water and immediately broken in a Riehle automatic cement testing machine, applying the load at the rate of 600 lb. per minute.

The detailed results of these tests are given in Table 1. It will be noted that these results are quite uniform, *i. e.*, the variation in the strength of the briquettes of the same sand at the same age is small. The sands were ranked in the order of the tensile strength of the mortars at ninety days. This ranking is shown in Table 4.

6. *Cleanness*.—The sands were tested for cleanness as follows: 1,000 grams of the sand were thoroughly agitated in about one gallon of water. The mixture was then allowed to settle for about one minute, experience showing that this allowed sufficient time for the finest sand to settle. The dirty water was then siphoned off with a  $\frac{1}{4}$  in. rubber tube, care being taken that none of the sand was carried over with the water. This washing process was repeated until the water showed no discoloration. It was usually found necessary to “scrub” the dirtier sands between the hands to entirely remove the coating of clay from the grains. The sand was then transferred to a pan and as much water as possible drawn off by jarring the sand until the water flushed to the surface, and then removing the water with a pipette. The sand was then re-dried over the steam coil and weighed. The loss in weight due to the washing was taken as the amount of suspended matter.

The time required to accomplish this washing varied from about fifteen minutes for a fairly clean sand to about two and one-half hours for the dirtiest, the average being about one hour. The results of these tests are given in Tables 2 and 4.

7. *Sieve Analysis*.—The following standard sieves were used: Nos. 5, 8, 10, 16, 20, 30, 40, 60, 74, 100, 150, and 200. In some of the earlier tests sieves Nos. 5, 10, 15, 150, and 200 were omitted. The sieves were nested in order of size, the largest at the top. The washed sand was then placed on the top sieve and the whole shaken for forty minutes on a Per Se Sieve Agitator driven by power at 100 r. p. m. After shaking,



TABLE 2.  
SIEVE ANALYSIS.

Sand.		Percent by Weight Passing Sieve No.													
No.	Name.	Suspended Matter.	200	150	100	74	60	40	30	20	16	10	8	5	0.2 in.
1	Chicago, K. I. Co.	0.3	...	...	4.2	48.6	69.5	96.4	99.1	99.7	99.8	...	100.0	...	100.0
2	Chicago, Z.-R. Co.	0.3	...	...	2.5	20.0	25.9	77.3	87.5	93.7	94.7	...	99.1	...	100.0
3	Chicago, K. I. Co.	0.0	...	...	2.4	9.9	13.9	49.1	69.0	78.3	79.8	...	89.1	...	100.0
4	Limestone Scr...	0.0	...	...	8.1	9.3	10.7	14.9	15.5	19.9	21.2	...	52.3	...	100.0
5	Elgin .....	1.0	...	...	2.8	5.0	7.4	20.9	36.4	51.7	55.0	...	84.0	...	100.0
6	Elgin .....	0.9	...	...	2.1	5.2	9.0	23.6	39.2	60.1	65.5	...	97.3	...	100.0
7	Bloomington .....	8.0	9.0	9.7	11.4	19.8	21.7	43.0	56.5	67.2	69.9	85.8	92.1	96.6	100.0
8	Rockford .....	0.6	...	...	1.7	5.5	10.8	25.1	34.3	60.0	68.2	...	98.0	...	100.0
9	Lincoln .....	1.1	...	...	2.4	4.1	6.5	26.7	46.4	61.7	65.8	...	95.4	...	100.0
10	Alton .....	0.3	...	...	1.2	5.2	10.5	45.6	70.2	87.8	90.3	...	98.2	...	100.0
11	Alton .....	0.2	...	...	2.6	5.3	8.9	30.1	53.8	76.2	80.0	...	97.0	...	100.0
12	Covington, Ind..	1.5	...	...	3.6	5.7	7.6	19.8	31.6	47.9	53.3	...	93.5	...	100.0
13	Gladstone .....	0.2	...	...	1.1	6.8	12.9	63.8	88.8	97.0	97.9	...	99.8	...	100.0
14	Decatur .....	2.5	2.9	3.1	3.9	6.0	7.8	21.0	35.8	45.9	48.7	71.6	81.5	93.7	100.0
15	Freepot .....	1.3	3.0	3.7	6.6	14.4	18.5	43.9	63.6	79.2	82.5	97.2	99.2	99.9	100.0
16	Sandstone Scr...	0.0	...	...	0.2	1.4	4.2	30.9	63.2	82.9	86.4	...	98.3	...	100.0
17	Aurora .....	0.5	...	...	0.9	1.1	1.6	12.3	35.0	55.7	61.3	...	97.8	...	100.0
18	Joliet .....	18.3	19.3	19.5	20.2	21.1	22.2	32.5	63.7	94.8	96.9	99.5	99.7	99.9	100.0
19	Moline .....	0.0	0.0	0.1	0.2	1.6	4.3	35.2	67.1	85.8	88.6	96.9	98.3	99.4	100.0
20	Urbana .....	3.5	6.7	8.6	17.0	39.1	52.4	74.4	79.6	83.5	84.5	92.3	95.3	98.3	100.0
21	E. St. Louis .....	trace	0.4	0.7	1.8	5.9	9.9	33.5	55.1	73.4	82.6	95.9	97.8	99.4	100.0
22	Waukegan .....	0.0	0.1	0.2	0.8	3.8	12.1	38.4	61.7	82.0	85.8	98.0	99.0	100.0	100.0
23	Paris .....	1.2	1.7	2.1	4.3	12.9	16.9	64.4	91.4	97.6	98.1	99.1	99.4	99.8	100.0
24	Taylorville .....	4.0	7.4	9.4	22.1	55.6	75.4	99.5	99.8	99.9	99.9	99.9	99.9	99.8	100.0
25	Cairo .....	0.3	0.4	0.5	0.8	2.5	3.9	24.9	62.9	81.9	84.8	95.7	98.1	99.3	100.0
26	Hannibal, Mo....	0.2	0.3	0.4	0.9	3.9	7.4	33.2	58.5	76.9	80.4	93.3	96.1	99.3	100.0
27	Beardstown .....	4.4	6.6	7.6	13.2	35.3	47.4	97.0	99.6	99.9	99.9	99.9	100.0	100.0	100.0
28	Mt. Carmel .....	2.4	2.6	2.7	3.9	18.8	34.2	98.7	99.8	99.9	99.9	99.9	99.8	99.9	100.0
29	La Salle .....	3.2	4.2	4.5	6.8	16.5	26.0	87.6	97.7	99.1	99.3	99.7	99.8	99.9	100.0
30	Peoria .....	2.7	3.1	3.5	6.0	14.5	17.8	47.8	74.9	88.2	90.3	96.7	98.0	99.0	100.0
31	Peoria .....	1.9	2.3	2.4	2.6	3.0	4.0	20.0	59.5	83.6	86.5	96.2	97.9	99.3	100.0
32	Peoria .....	0.6	0.8	0.9	2.0	9.2	13.3	68.7	89.1	96.0	97.1	99.0	99.4	99.7	100.0

the sand retained on each sieve was weighed and from these weights the percentage passing each sieve was calculated. In making these calculations the amount of suspended matter, as determined by the cleanness test, was included with the material passing the finest sieve.

The results of these tests are given in Table 2 and are shown graphically in Figs. 1 to 4. The "size of grains" used in platting these curves is the nominal clear opening of the sieve meshes. The use of these curves is more fully discussed under Size and Gradation of Grains on page 29.

8. *Specific Gravity.*—The specific gravity of the sands was determined by means of a Schumann specific gravity flask. This flask consists of a bulb or bottle into the neck of which a graduated stem fits with a ground joint. The bulb was filled with water and the height of the column of water in the stem read from the graduations. Fifty grams of sand were admitted, care being taken to permit the escape of the air, and

TABLE 3.  
SPECIFIC GRAVITY, VOIDS, AND WEIGHT.

No.	Sand. Name.	D, Water Displaced by 100 G. Sand Cu. Cm.	Specific Gravity, 100 D	S, 500xSp. Gr.	W, Weight of 500 c.c. of Sand, Grams.	Voids, S—W S Percent.	Weight Per Cu. Ft. Pounds.
0	Standard .....	37.57	2.660	1330.0	870.0	84.6	108.7
1	Chicago, K. I. Co. ....	37.62	2.655	1327.5	847.0	86.2	105.8
2	Chicago, Z.-R. Co. ....	37.65	2.655	1327.5	871.0	84.4	108.8
3	Chicago, K. I. Co. ....	37.13	2.695	1347.5	922.0	81.6	115.1
4	Limestone screenings...	36.40	2.750	1375.0	988.0	28.5	122.8
5	Elgin .....	36.69	2.720	1360.0	926.0	81.9	115.7
6	Elgin .....	37.27	2.680	1340.0	916.0	81.6	114.4
7	Bloomington .....	38.10	2.625	1312.5	911.5	30.5	113.8
8	Rockford .....	37.51	2.665	1332.5	905.0	32.0	113.0
9	Lincoln .....	37.72	2.650	1325.0	895.5	32.4	111.9
10	Alton .....	38.03	2.630	1315.0	901.0	81.5	112.5
11	Alton .....	37.57	2.660	1330.0	917.0	31.0	114.5
12	Covington, Ind. ....	37.60	2.660	1330.0	884.5	33.5	110.4
13	Gladstone .....	37.65	2.655	1327.5	852.0	35.8	106.3
14	Decatur .....	37.60	2.660	1330.0	927.5	80.3	115.8
15	Freeport .....	36.80	2.720	1360.0	912.0	83.0	113.9
16	Sandstone screenings...	36.97	2.705	1352.5	899.0	88.0	112.2
17	Aurora .....	36.75	2.720	1360.0	894.0	34.2	111.7
18	Joliet .....	37.60	2.660	1330.0	802.0	39.7	100.2
19	Moline .....	37.77	2.650	1325.0	897.0	32.3	112.0
20	Urbana .....	37.75	2.650	1325.0	861.0	35.0	107.5
21	East St. Louis. ....	37.73	2.650	1325.0	927.0	80.1	115.8
22	Waukegan .....	37.25	2.680	1340.0	901.0	82.7	112.5
23	Paris .....	37.52	2.665	1332.5	867.0	85.2	108.3
24	Taylorville .....	37.88	2.635	1317.5	798.5	39.4	99.7
25	Cairo .....	37.79	2.645	1322.5	868.0	34.7	107.8
26	Hannibal, Mo. ....	37.88	2.680	1340.0	921.0	31.3	115.0
27	Beardstown .....	38.40	2.605	1302.5	809.0	37.9	101.0
28	Mt. Carmel .....	37.90	2.635	1317.5	835.5	36.5	104.4
29	La Salle .....	37.70	2.650	1325.0	854.0	35.5	106.7
30	Peoria .....	37.50	2.665	1332.5	908.5	32.9	111.9
31	Peoria .....	37.80	2.640	1320.0	832.0	86.9	103.9
32	Peoria .....	37.61	2.660	1330.0	870.0	84.6	108.7



the new height of the water column read. The difference in the two readings gave the volume of water displaced by the fifty grams of sand. A second fifty grams of sand was immediately admitted in order to secure a double determination as well as a check on the observations. From these data the specific gravity of the sand was computed. The results of these tests are shown in Tables 3 and 4.

9. *Voids*.—The large variation in the percentage of voids in sands as determined by different observers is doubtless due to errors of observation, particularly to a failure to compact all sands to the same extent. For the present series of tests some method of operation was desired which would compact all sands alike, and hence yield reliable results; and, further, a method was desired which would be easy to perform and which could make use of a limited quantity of sand. After a number of trials the following method was adopted:

A graduated cylinder about 2 in. in diameter and of 500 c.c. capacity was used. About 20 c.c. of sand was placed in this cylinder and compacted by striking lightly with the cylinder on a pad composed of eight thicknesses of heavy cotton flannel. Twelve blows were given at the rate of about two per second with a fall of about one inch, care being taken that the blow was not hard enough to cause the sand to bounce and also that the cylinder struck squarely so that the sand was not thrown from side to side. Successive increments of the sand were added in this way until the cylinder was filled. The difference between the weight of the empty cylinder and the cylinder full of sand gave the weight of 500 c.c. of dry compacted sand. Then, knowing the specific gravity of the sand, the percentage of voids was computed from the equation

$$V=100 \frac{S-W}{S}$$

in which  $V$  is the voids expressed in percents of the total volume,  $W$  is the weight of the sand, and  $S$  is the product of the volume of the sand, its specific gravity, and the weight of a unit volume of water; *i. e.*,  $S$  is the weight of an equal volume of sand containing no voids. In the present case  $S$  equals 500 multiplied by the specific gravity.

The results obtained by this method were quite uniform. The maximum variation from the mean of five determinations of the weight of 500 c.c. of the same sand made by the same observer was only 7.5 grams or about 0.8 per cent. The maximum variation from the mean of four sets of determinations on the same sands by four different observers was only 1.5 per cent. The results of these tests are given in Tables 3 and 4,

10. *Weight.*—The weight per cubic foot of each sand was computed from the weight of 500 c.c. and is given in Tables 3 and 4. These results average about 3 per cent higher than the results obtained by other observers on similar sands; but it is believed that this is due to a difference in the method of compacting the sands, and also that the results given here are more nearly correct for the dry sands after being transported some distance in wagons or cars.

TABLE 4.  
SUMMARY OF DATA.

Sand.			Tensile Strength of 1:3 Mortar at 90 Days.			Rank According to Tensile Strength	Voids, Per Cent.	Weight per Cu. Ft., Pounds.	Suspended Matter, Per Cent.	Specific Gravity.
No.	Name.	Kind.	Pounds per Sq. In.	In Per Cent of the Strength of						
00	Neat cement...	Portland	785	213.4	100.0	..	...	...	...	....
0	Ottawa standard	20-30	368	100.0	46.9	7	34.6	108.7	0.0	2.660
1	Chicago K. I. Co	Lake	205	55.7	26.1	27	36.2	105.8	0.3	2.655
2	Chicago Z-R Co	Lake	311	84.5	39.6	11	34.4	108.8	0.3	2.655
3	Chicago K. I. Co	Lake	314	85.4	40.0	10	31.6	115.1	0.3	2.695
4	Limestone scr..	Joliet	485	131.8	61.8	1	28.5	122.8	0.0	2.750
5	Elgin, Hammond pit .....	Bank	464	126.0	59.1	2	31.9	115.7	1.0	2.720
6	Elgin, Stimpson pit .....		410	111.5	52.2	5	31.6	114.4	0.9	2.680
7	Bloomington ..	Bank	286	77.8	36.4	17	30.5	113.8	8.0	2.625
8	Rockford .....	Bank	386	104.9	49.2	6	32.0	113.0	0.6	2.665
9	Lincoln .....	Bank	303	82.4	38.6	14	32.4	111.9	1.1	2.650
10	Alton .....	River	269	73.2	34.3	20	31.5	112.5	0.3	2.630
11	Alton .....	River	280	76.2	35.7	18	31.0	114.5	0.2	2.660
12	Covington, Ind.	Bank	310	84.4	39.5	12	33.5	110.4	1.5	2.660
13	Gladstone .....	Bank	241	65.5	30.7	25	35.8	106.3	0.2	2.655
14	Decatur .....	Bank	428	116.4	54.5	4	30.3	115.8	2.5	2.660
15	Freeport .....	Bank	317	86.2	40.4	9	33.0	113.9	1.3	2.720
16	Sandstone sci...	Freeport	269	73.2	34.3	20	33.0	112.2	0.0	2.705
17	Aurora .....	Bank	454	123.3	57.8	3	34.2	111.7	0.5	2.720
18	Joliet .....	Bank	159	43.3	20.3	31	39.7	100.2	18.3	2.660
19	Moline .....	River	257	69.8	32.7	24	32.3	112.0	0.0	2.650
20	Urbana .....	Bank	330	89.7	42.0	8	35.0	107.5	3.5	2.650
21	E. St. Louis...	River	258	70.2	32.8	23	30.1	115.8	Trace	2.650
22	Waukegan .....	Lake	296	80.5	37.7	16	32.7	112.5	0.0	2.630
23	Paris .....	Bank	259	70.4	33.0	22	35.2	108.3	1.2	2.665
24	Taylorville....	Bank	211	57.4	26.9	26	39.4	99.7	4.0	2.635
25	Cairo .....	River	298	81.0	38.0	15	34.7	107.8	0.3	2.645
26	Hannibal, Mo..	River	279	75.8	35.5	19	31.3	115.0	0.2	2.680
27	Beardstown....	Bank	140	38.1	17.9	32	37.9	101.0	4.4	2.605
28	Mt. Carmel....	River	170	46.2	21.7	30	36.5	104.4	2.4	2.635
29	La Salle.....	Bank	194	52.7	24.7	28	35.5	106.7	3.2	2.650
30	Peoria .....	Bank	262	71.2	33.4	21	32.9	111.9	2.7	2.665
31	Peoria .....	Bank	306	83.2	39.0	13	36.9	103.9	1.9	2.640
32	Peoria .....	River	178	48.4	22.7	29	34.6	108.7	0.6	2.660

11. *Mineralogical Composition and Sharpness.*—The sands were examined under a magnifying glass having a power of about five diameters to determine the approximate mineralogical composition, the sharpness or irregularity in shape of the grains, and the roughness of the surfaces. The results are therefore only relative and hence are not tabulated but are given in connection with the description of the sands.



## III. DESCRIPTION OF SANDS.

The following description of the sands is based on the results of the tests and on general information furnished by the parties who sent the sands. The general appearance of the sands is well shown by Figs. 6 to 11, inclusive, which are reproduced from photographs. In making these photographs care was taken to secure a representative surface of the sand, and as the illustrations are full size the relative appearance and fineness of the different sands are well indicated.

*Sample No. 0* (See Fig. 6).—This is the standard sand used in the comparative tests of cements. It is pure quartz and comes from the St. Peter formation near Ottawa, Ill. The grains are spherical, almost transparent with dull surfaces, and are nearly of the same size, since the sand is screened to pass a No. 20 sieve and be retained on a No. 30. The specific gravity is 2.66, the percentage of voids 34.6, and the weight per cu. ft. 108.7 lb. The tensile strength of 1:3 mortar at 90 days was 368 lb. per sq. in., or 46.9 per cent of that of the neat cement. This sand ranked seventh in strength, *i. e.*, only six other sands produced mortars of greater strength.

*Sample No. 1* (See Fig. 6).—This sand, supplied by the Knickerbocker Ice Co., Chicago, was taken from banks along the shore of Lake Michigan. Its color is light yellow, and the grains are angular and consist principally of quartz. This sand is very fine, 99.8 per cent passing the No. 16, and 69.5 per cent the No. 60 sieve (see Fig. 1). There is 3 per cent of suspended matter, and the specific gravity is 2.655, the percentage of voids 36.2, and the weight per cu. ft. 105.8 lb. The tensile strength of 1:3 mortar at 90 days was 205 lb. per sq. in., 55.7 per cent of the strength of the Ottawa standard sand mortar. It ranks twenty-seventh in strength.

*Sample No. 2* (See Fig. 6).—This is also a bank sand from the shores of Lake Michigan and was supplied by the Zander-Reum Company, Plasterers, Chicago. It is light gray in color and is composed principally of quartz with a small proportion of granite, flint, and limestone. It is somewhat better graded than the preceding sample (see Fig. 1), 94.7 per cent passing the No. 16 sieve and 25.9 per cent the No. 60. It contains 3 per cent of suspended matter, the specific gravity is 2.655, the weight per cu. ft. is 109.8 lb., and the percentage of voids is 34.4. The strength of 1:3 mortar at 90 days was 311 lb. per sq. in., 84.5 per cent of that of the Ottawa standard sand mortar. It ranks eleventh in strength.

*Sample No. 3* (See Fig. 6).—This is another lake sand furnished by the Knickerbocker Ice Co., Chicago. The smaller grains are principally quartz, while the larger grains are composed of granite, flint, limestone, and chert, which give the sand its light gray color. It is better graded than either of the preceding samples (see Fig. 1), and the percentage of voids is somewhat lower than would be expected of a sand of this grading, being only 31.6. It contains 3 per cent of suspended matter, the specific gravity is 2.695, and the weight per cu. ft. is 115.1 lb. The tensile strength of 1:3 mortar at 90 days was 314 lb. per sq. in., 85.4 per cent of that of the Ottawa standard sand mortar. It ranks tenth in strength.

*Sample No. 4* (See Fig. 6).—This is a sample of Joliet limestone screenings which is being used in Chicago to a considerable extent. The stone is very close and even-grained and of a pale blue tint. In crushing some of it passes into very fine dust, but there is no suspended matter. The specific gravity is 2.75, the weight per cu. ft. is 122.8 lb., and the percentage of voids is 28.5. The sieve analysis curve (see Fig. 1) shows that this sample is almost uniformly graded. The tensile strength of a 1:3 mortar at 90 days was 485 lb. per sq. in., 131.8 per cent of the Ottawa standard sand mortar, and was the highest tensile strength of mortar recorded in these tests. From this one sample it would appear that limestone screenings give a much stronger mortar than natural sand; but it will be noted that this sample is particularly well graded, has very little fine dust, and the stone itself is uniform and hard, hence this sample should be regarded as exceptional and not as typical.

*Sample No. 5* (See Fig. 6).—This sample of sand comes from the Hammond pit of the Chicago Gravel Company near Elgin. It is yellowish gray in color and contains less quartz than the average Illinois sand. The other materials present are principally limestone, flint, and chert. This is one of the coarsest sands tested, only 55 per cent passing the No. 16 sieve and 7.4 per cent the No. 60. (See Fig. 1.) Although this sand was reported as a "washed sand", it contains 1 per cent of suspended matter, a trifle more than Sample No. 6 which is a "screened" sand from the same locality. The specific gravity is 2.72, the weight per cu. ft. 115.7 lb., and the percentage of voids 31.9. This sand made the strongest mortar of the natural sands, being second only to the limestone screenings. The strength of a 1:3 mortar at 90 days was 464 lb. per sq. in., 126 per cent of that of the Ottawa standard sand mortar.

*Sample No. 6* (See Fig. 7).—This is a screened sand from the



Stimpson pit, near Elgin. It is grayish in color and contains a small proportion of flint, granite, and chert, the majority of the material being quartz. Note that in this respect it differs quite a little from the preceding sample from the same locality. This sand is somewhat exceptional in that the fine grains are the more angular, the large grains being well rounded. The sieve analysis (see Fig. 1) shows this sand to be somewhat finer than sample No. 5. The specific gravity is 2.68, the weight per cu. ft. 114.4 lb., and the percentage of voids 31.6. A 1:3 mortar gave a strength of 410 lb. per sq. in. at 90 days, 111.5 per cent of that of the Ottawa standard sand mortar. This sand ranks fifth in tensile strength.

*Sample No. 7* (See Fig. 7).—This is a bank sand obtained along Sugar Creek near Bloomington. It is quite uniform in quality, and has been used a great deal for pavement cushions and in common brick work, but has not been used to any great extent in concrete, as it was thought to be too dirty. It contains 8 per cent of suspended matter in the form of finely divided clay which is distributed loosely throughout the mass of the sand and does not form a coating on the grains. The tensile tests (see Table 1) show that it forms a mortar considerably stronger than several of the cleanest river sands; and since it is fairly well graded (see Fig. 1), and its mineralogical composition is satisfactory, it could doubtless be safely used in nearly all kinds of work. The tensile strength was not improved by washing the sand. The specific gravity is 2.625, the weight per cu. ft. 113.8 lb., and the percentage of voids 30.5. The tensile strength of a 1:3 mortar at 90 days was 286 lb. per sq. in., 67.7 per cent of that of the Ottawa standard sand mortar. It ranks seventeenth in tensile strength.

*Sample No. 8* (See Fig. 7).—This is a bank sand from near Rockford. The deposits are large and very uniform in quality. The sand is light gray in color and contains considerable chert with some limestone and flint. The sieve analysis (see Fig. 1) shows it to be fairly well graded. The amount of suspended matter is 6 per cent, the specific gravity 2.665, the weight per cu. ft. 113 lb., and the percentage of voids 32.0. This sand ranks sixth in tensile strength, a 1:3 mortar giving a strength of 386 lb. per sq. in. at 90 days, 104.9 per cent of the strength of the Ottawa standard sand mortar.

*Sample No. 9* (See Fig. 7).—This is a sample of the sand used in the construction of the Illinois Supreme Court building at Springfield. It is a bank sand from near Lincoln, and is dark gray in color due to nearly half of its mass being composed of dark colored flints and granites,

the remainder being principally quartz with some limestone. It is fairly well graded (see Fig. 2), 65.8 per cent passing the No. 16 sieve and 6.5 per cent the No. 60. It contains 1.1 per cent of clay which adheres to the grains and which possibly accounts for the lower tensile strength than appears to be indicated by the other characteristics of the sand; but this can not be stated definitely as no test was made on the washed sand. It ranks fourteenth in tensile strength, a 1:3 mortar showing a strength of 303 lb. per sq. in. at 90 days, 82.4 per cent of the strength of the Ottawa standard sand mortar. The specific gravity is 2.65, the weight per cu. ft. 111.9 lb., and the percentage of voids 32.4.

*Sample No. 10* (See Fig. 7).—This is a bar sand from the Mississippi River near Alton. It is dark gray in color, and contains some limestone and flint. There is 3 per cent of suspended matter present. The sieve analysis (see Fig. 2) shows it to be very fine, 90.3 per cent passing the No. 16 sieve. The specific gravity is 2.63, the weight per cu. ft. 112.5 lb., and the percentage of voids 31.5. The tensile strength of 1:3 mortar at 90 days was 269 lb. per sq. in., 73.2 per cent of that of the Ottawa standard sand mortar. It ties with sample No. 16 for twentieth place in the order of tensile strength.

*Sample No. 11* (See Fig. 7).—This is also a bar sand from near Alton. It is brownish gray in color and contains some flint and limestone. There is also a small amount of coal and cinders present, probably as the result of transportation by rail. The finer grains are well rounded but the coarser ones are quite angular. This sand is quite fine although not quite as fine as sample No. 10 (see Fig. 2). The specific gravity is 2.66, the weight per cu. ft. 114.5 lb., the percentage of voids 31.0, and the suspended matter amounts to 2 per cent. It ranks eighteenth in tensile strength, a 1:3 mortar having a strength of 280 lb. per sq. in. at 90 days, 76.2 per cent of that of the Ottawa standard sand mortar.

*Sample No. 12* (See Fig. 8).—This sand, used in large quantities in and about the cities of Champaign and Urbana, is a bank sand from along the Wabash River near Covington, Ind. It is yellowish gray in color and contains some limestone, flint, and shale. The grains are all well rounded. This sand is fairly well graded but has an excess of material between the No. 8 and No. 16 sieves (see Fig. 2). It contains 1.5 per cent of suspended matter in the form of loose clay. The specific gravity is 2.66, the weight per cu. ft. 110.4 lb., and the percentage of voids 33.5. The tensile strength of 1:3 mortar at 90 days was 310 lb. per sq. in., 84.4 per cent of that of the Ottawa standard sand mortar. This sand ranks twelfth in tensile strength.



*Sample No. 13* (See Fig. 8).—This is a bank sand from near Gladstone. It is gray in color and contains some flint and granite, the grains being moderately angular. It is quite fine, 97.9 per cent passing the No. 16 sieve and 12.9 per cent the No. 60 (see Fig. 2). This is the cleanest of the bank sands, there being but 0.2 per cent of suspended matter present. The specific gravity is 2.655, the weight per cu. ft. 106.3 lb., and the percentage of voids 35.8. It ranks twenty-fifth in tensile strength, a 1:3 mortar showing a strength at 90 days of 241 lb. per sq. in., 65.5 per cent of that of the Ottawa standard sand mortar.

*Sample No. 14* (See Fig. 8).—This sand is screened from bank gravel found along the Sangamon River near Decatur. It is brownish gray in color and contains considerable flint, granite, limestone, and shale, with some softer rocks containing iron oxide. As shown by Fig. 2, this is the coarsest sample of natural sand tested. It might therefore be expected that this sand would yield a mortar next in strength to the limestone screenings, and it probably would but for the fact that many of the grains are so soft that they were ruptured in the tensile tests, showing that they were weaker than the adhesion of the cement to them. In spite of this it makes a very strong mortar, ranking fourth in this respect, a 1:3 mixture having a strength at 90 days of 428 lb. per sq. in., 116.4 per cent of that of the Ottawa standard sand mortar. The specific gravity is 2.66, the weight per cu. ft. 115.8 lb., and the percentage of voids 30.3.

*Sample No. 15* (See Fig. 8).—This is a bank sand from near Freeport. It is yellow in color due to 1.3 per cent of clay which adheres very tightly to the sand grains. It is composed principally of quartz with some flint, limestone, and granite. It is moderately fine, 82.5 per cent passing the No. 16 sieve (see Fig. 2). The specific gravity is high, being 2.72; and the grains are quite hard and well rounded. This sand would probably be improved by washing, provided it could be done without washing out the fine sand, since the suspended matter forms a coating on the grains. The tensile strength of 1:3 mortar was 317 lb. per sq. in. at 90 days, 86.2 per cent of that of the Ottawa standard sand mortar. It ranks ninth in tensile strength. The weight per cu. ft. is 113.9 lb. and the percentage of voids 33.0.

*Sample No. 16* (See Fig. 8).—This is a sample of Freeport sandstone screenings. The stone is rather soft which probably accounts for the comparatively low tensile strength, the fragments themselves being frequently ruptured in the tests. This sample is deficient in fine material (see Fig. 2), only 4.2 per cent passing the No. 60 sieve. This is due

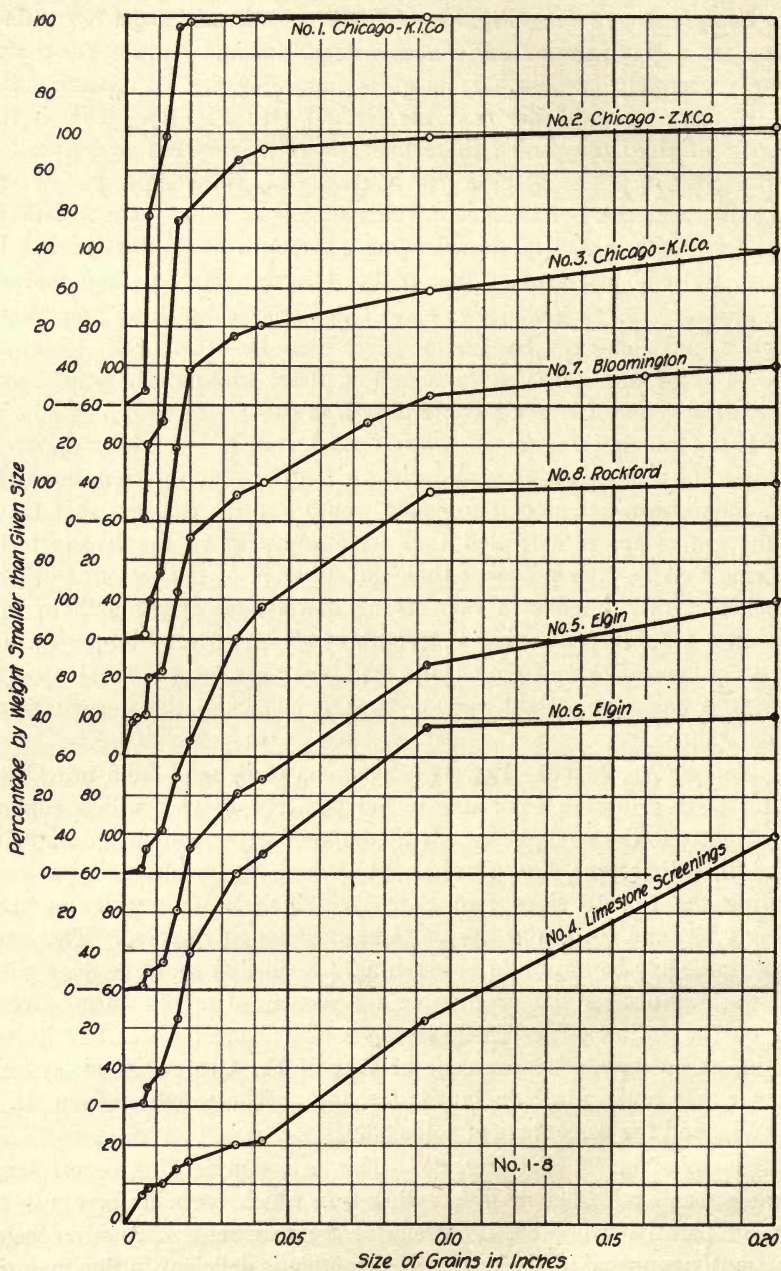


FIG. 1. SIEVE ANALYSIS CURVES FOR SAMPLES 1 TO 8.



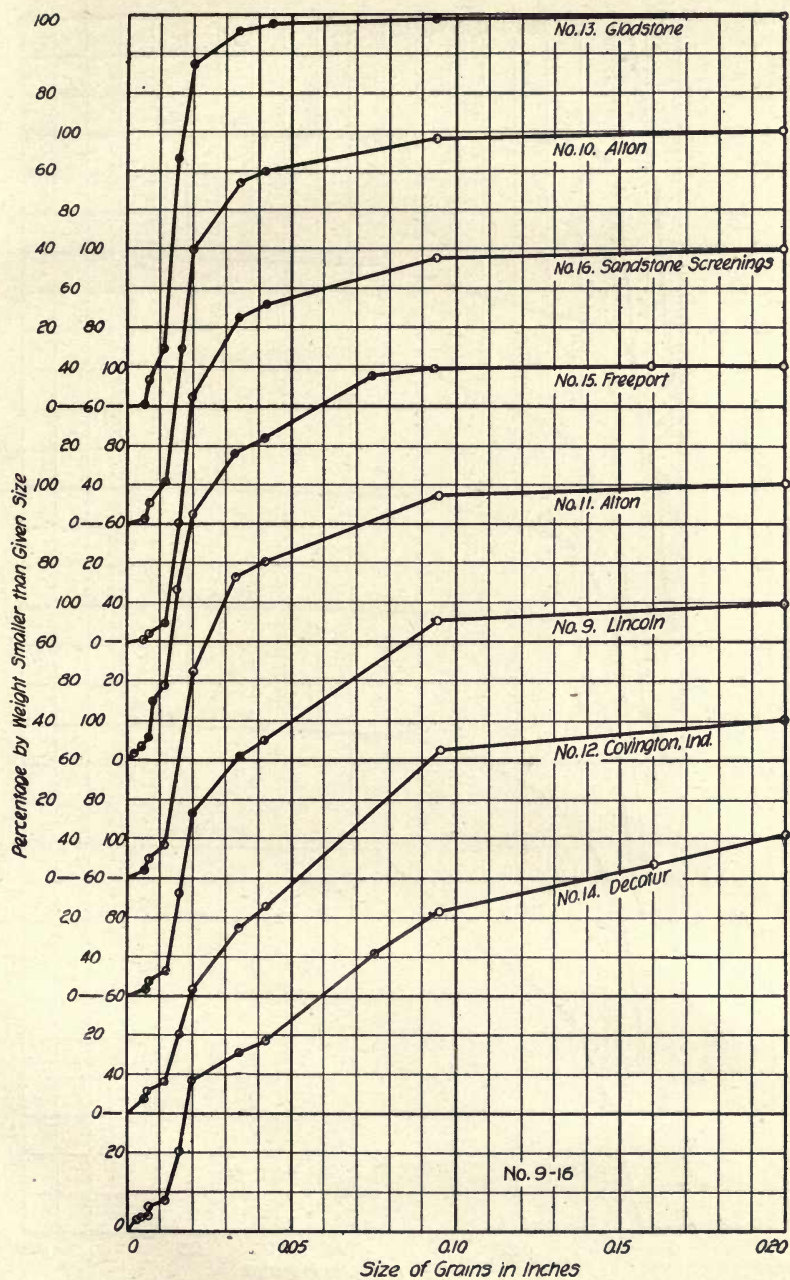


FIG. 2. SIEVE ANALYSIS CURVES FOR SAMPLES 9 TO 16.

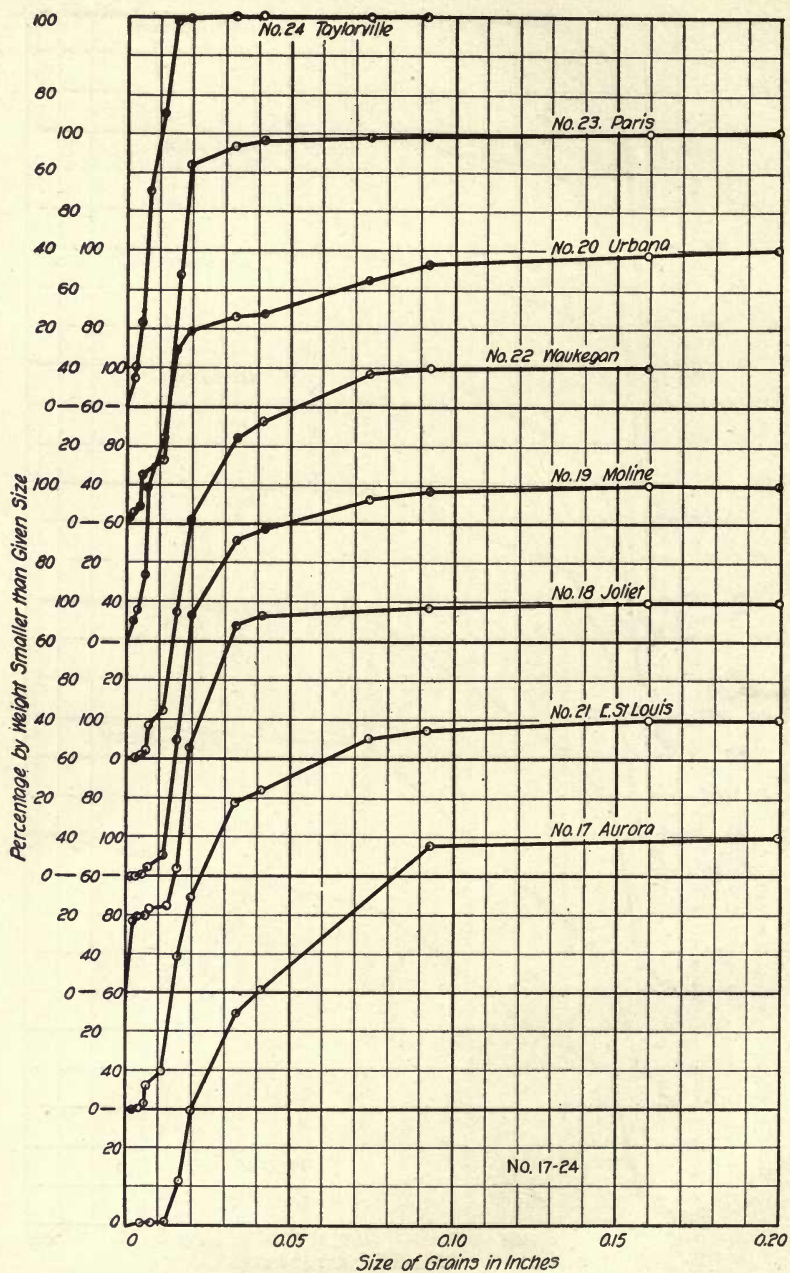


FIG. 3. SIEVE ANALYSIS CURVES FOR SAMPLES 17 TO 24.



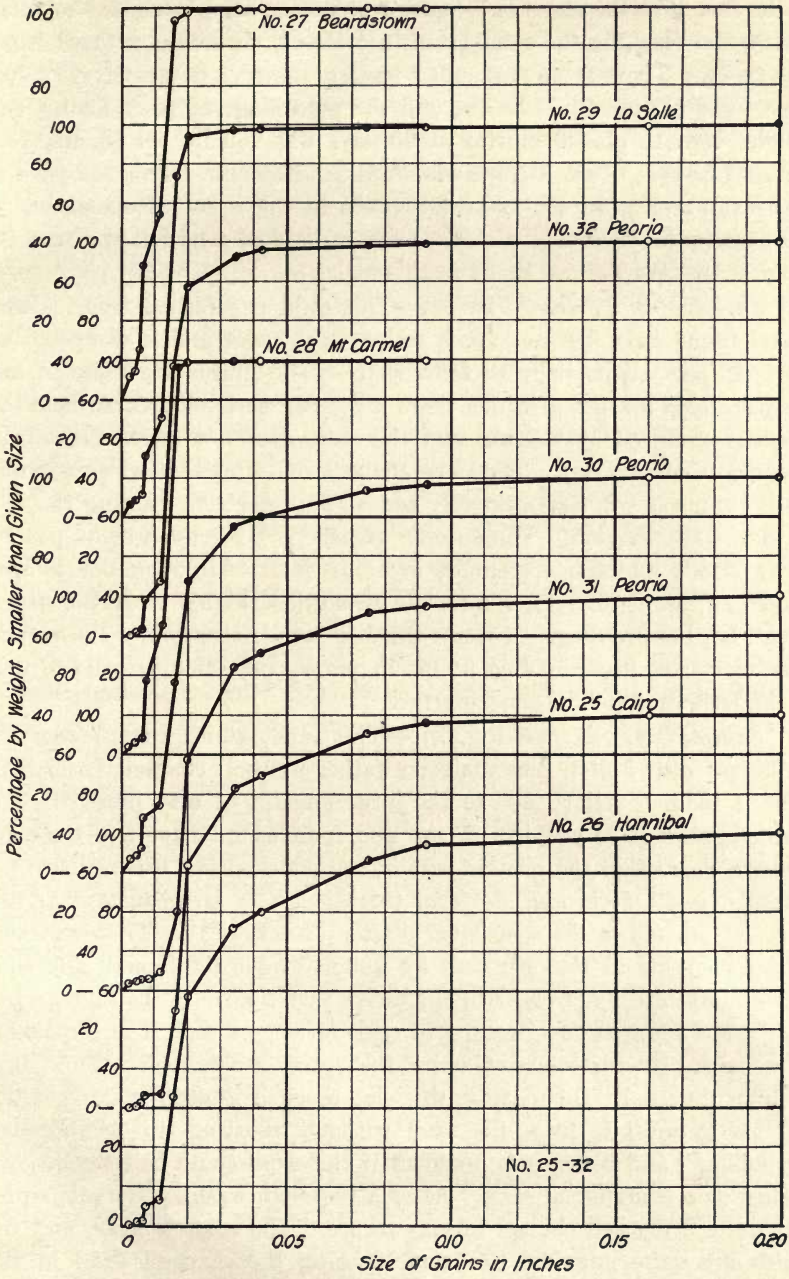


FIG. 4. SIEVE ANALYSIS CURVES FOR SAMPLES 25 TO 32,

to the fact that the stone is composed of quartz sand cemented together and in the crushing the sand grains are simply separated without being broken up. There is no suspended matter, the specific gravity is 2.705, the weight per cu. ft. 112.2 lb., and the percentage of voids 33.0. The tensile strength of 1:3 mortar at 90 days was 269 lb. per sq. in., 73.2 per cent of that of the Ottawa standard sand mortar. This sample ties with sample No. 10 for twentieth place in the order of strength. It compares quite favorably with the average natural sand but it is not the equal of the best natural sands in this series.

*Sample No. 17* (See Fig. 8).—This sand is screened from a bank gravel found near Aurora. It is yellowish in color and is composed almost entirely of quartz with some shale. The grains are rounded and the suspended matter, of which there is 0.5 per cent, adheres to them but is easily removed by wetting and therefore does not affect the tensile strength of the mortar. The sieve analysis indicates that while not well graded this sand is comparatively coarse, 61.3 per cent passing the No. 16 sieve (see Fig. 3). The specific gravity is 2.72, the weight per cu. ft. 111.7 lb., and the percentage of voids 34.2. Although not as well graded as sample No. 14, the tensile strength is higher since the grains are all hard and strong. It ranks third in tensile strength, a 1:3 mortar showing a strength at 90 days of 454 lb. per sq. in., 123.3 per cent of that of the Ottawa standard sand mortar.

*Sample No. 18* (See Fig. 9).—This sand, which comes from the Fuller pit near Joliet, presents some rather unusual characteristics. The color is reddish yellow, due to the large amount of clay present. The grains appear quite uniform in size and rounded in shape and the sieve analysis shows that the greater part of the material lies between the No. 20 and No. 60 sieves and also that there is a very large amount of fine material, including the suspended matter (see Fig. 3). The suspended matter amounts to 18.3 per cent by weight of the total sand, and consists almost entirely of clay which adheres very tightly to the sand grains, each grain being entirely coated to such an extent that it is impossible to recognize the materials of which the grains are formed without first washing the sand. On wetting, this clay becomes gummy making it impossible to wash it from the sand without resorting to a thorough "scrubbing", and hence it is doubtful if this sand could be economically washed on a commercial scale. After a thorough washing the sands present quite a marked change in appearance. The color is gray, and the grains are quite angular, this sample being the sharpest sand in the series with the exception of sample No. 21. The composition is shown



to be about half quartz, the other materials being limestone and granite with large proportions of shale and other soft rocks. The sand as a whole is of very poor quality, due to the large amount of soft materials, the poor grading, and the abnormal amount of suspended matter and the way in which it coats the sand grains. The unwashed sand ranked thirty-first (next to lowest) in tensile strength, a 1:3 mortar having a strength at 90 days of only 159 lb. per sq. in., only 43.3 per cent of that of the Ottawa standard sand mortar. The tensile strength at 28 days (not tested at 90 days) was increased about 35 per cent by thoroughly washing the sand. The specific gravity is 2.66, the weight per cu. ft. 100.2 lb., and the percentage of voids 39.7.

*Sample No. 19* (See Fig. 9).—This is a bar sand from the Mississippi River a few miles above Moline. The bars are constantly shifting and therefore the sand is more or less variable in character. It is gray in color and is composed principally of quartz with some flint, limestone, and granite. It is quite fine, 88.6 per cent passing the No. 16 sieve (see Fig. 3). There is a decided deficiency of fine material as it contains no suspended matter and only 0.2 per cent passes the No. 100 sieve. As a result, the tensile strength is less than would be expected from the other characteristics of the sand, and it would probably improve the mortar to add some fine material to it. It ranks twenty-fourth in tensile strength, the strength of 1:3 mortar at 90 days being 257 lb. per sq. in., 69.8 per cent of that of the Ottawa standard sand mortar. The specific gravity is 2.65, the weight per cu. ft. 112 lb., and the percentage of voids 32.3.

*Sample No. 20* (See Fig. 9).—This sand, obtained from banks of limited extent near Urbana, is quite variable in quality but the sample used in these tests was fairly representative. It is yellowish in color and contains some granite, flint, shale, and chert. The grains are rounded and are coated to a considerable extent with clay of which there is 3.5 per cent. It is not well graded, there being a large amount of fine material and a fair proportion of coarse material, but a marked deficiency in grains of intermediate size (see Fig. 3). When wet the sand behaves considerably like quick-sand, and on drying shows a decided tendency to form lumps. The use of this sand has been practically abandoned on account of its variable character and the limited amounts available, and because a good sand of uniform quality (sample No. 12) can be shipped in at a price sufficiently low to compete with it. The specific gravity is 2.65, the weight per cu. ft. 107.5 lb., and the percentage of voids 35.0. The tensile strength of 1:3 mortar at 90 days was 330 lb. per sq. in., 89.7 per cent of that of the Ottawa standard sand mortar. This sand ranks eighth in tensile strength.

*Sample No. 21* (See Fig. 9).—This sand is dredged from the bed of the Mississippi River at East St. Louis and varies but little in quality. It is light gray in color and contains some granite and flint, but the bulk of the material is pure quartz and is almost transparent. This is the sharpest of the natural sands in this series, the grains being very irregular in shape with the edges only slightly rounded. The faces of the grains are all very smooth, those of quartz having the appearance of broken glass. The tensile strength of the mortar was doubtless reduced by this condition, since an examination of the broken briquettes showed that the cement did not adhere well to the grains. This sand is not well graded (see Fig. 3); but the percentage of voids is the lowest of the natural sands, being 30.1 per cent. This is probably due to the extreme "sharpness" of the sand. The specific gravity is 2.65, and the weight per cu. ft. 115.8 lb. The tensile strength of 1:3 mortar at 90 days was 258 lb. per sq. in., 70.2 per cent. of that of the Ottawa standard sand mortar. It ranks twenty-third in strength.

*Sample No. 22* (See Fig. 9).—This sand is taken from the shore of Lake Michigan near Waukegan and varies in quality from time to time, as the result of storms. This sample is dark gray in color. The principal components are quartz, flint, limestone, granite, sandstone, and shale. There is also a considerable amount of coal and cinders present, the quantities of each indicating that their presence can not be attributed to transportation. This sand is quite fine, 85.8 per cent passing the No. 16 sieve (see Fig. 3). The specific gravity is 2.68, the weight per cu. ft. 112.5 lb., and the percentage of voids 32.7. It ranks sixteenth in strength, 1:3 mortar showing a tensile strength at 90 days of 296 lb. per sq. in., 80.5 per cent of that of the Ottawa standard sand mortar.

*Sample No. 23* (See Fig. 9).—This is a bank sand from limited but uniform deposits near Paris, Ill. It is very fine, 98.1 per cent passing the No. 16 sieve, and there is only an occasional large grain (see Fig. 3). The grains are all well rounded and are composed principally of quartz with some limestone and chert. The color is pale yellow. The suspended matter amounts to 1.2 per cent, the specific gravity is 2.665, the weight per cu. ft. 108.3 lb., and the percentage of voids 35.2. It ranks twenty-second in tensile strength, 1:3 mortar having a strength at 90 days of 259 lb. per sq. in., 70.4 per cent of that of the Ottawa standard sand mortar. This sand is too fine to be desirable for ordinary purposes, but if the large grains were screened out it would form an excellent grout sand.

*Sample No. 24* (See Fig. 10).—This is a bank sand from limited



but very uniform deposits near Taylorville. The mortar made of this sand is reported as working best when the proportion of cement is small, and considerable quantities of it have been used this way, but as would be expected it has not proved satisfactory. The sand is light yellow in color and the grains are well rounded. The principal components are quartz, limestone, and shale. This sand is the finest in this series, 100 per cent passing the No. 16 sieve, 99.5 per cent the No. 40, and 75.4 per cent the No. 60 (see Fig. 3). It is also the lightest sand, its weight per cu. ft. being only 99.7 lb. There is 4 per cent of suspended matter, and the sand shows a decided tendency to form lumps on drying. The specific gravity is 2.635 and the percentage of voids 39.4. The tensile strength of 1:3 mortar at 90 days was 211 lb. per sq. in., 57.4 per cent of that of the Ottawa standard sand mortar. It ranks twenty-sixth in tensile strength. Like sample No. 23 this sand is too fine for ordinary purposes but would be quite satisfactory as a grout sand.

*Sample No. 25* (See Fig. 10).—This sand, furnished by the Halliday Sand Company, Cairo, is pumped from the bed of the Ohio River above that city. It is gray in color and contains some granite and limestone, the grains all being somewhat rounded. It is moderately fine (see Fig. 4), and is deficient in both coarse and very fine grains. The suspended matter amounts to 0.3 per cent. The specific gravity is 2.645, the weight per cu. ft. 107.8 lb., and the percentage of voids 34.7. The tensile strength of 1:3 mortar at 90 days was 298 lb. per sq. in., 81 per cent of that of the Ottawa standard sand mortar. This sand ranks fifteenth in strength.

*Sample No. 26* (See Fig. 10).—This sand is taken from the bed of the Mississippi River near Hannibal, Mo. It is bluish gray in color and contains considerable flint, granite, and chert, all of the grains being moderately round. The sieve analysis shows it to be deficient in both coarse and very fine grains (see Fig. 4). There is 0.2 per cent of suspended matter present. The specific gravity is 2.68, the weight per cu. ft. 115 lb., and the percentage of voids 31.3. It ranks nineteenth in tensile strength, 1:3 mortar showing a strength at 90 days of 279 lb. per sq. in., 75.8 per cent of that of the Ottawa standard sand mortar.

*Sample No. 27* (See Fig. 10).—This is a bank sand from deposits of more or less variable character near Beardstown. It is reddish yellow in color due to the 4.4 per cent of reddish clay which forms a coating around the grains. It contains some granite, limestone, flint, and considerable amounts of soft materials, and shows a tendency to form lumps. The sieve analysis (see Fig. 4) shows that this sand is next in fineness to

sample No. 24, practically all passing the No. 16 sieve and 47.4 per cent the No. 60. This sand has been used a great deal for pavement foundations, common brick work, etc., and has given fairly satisfactory service although it is entirely too fine and too deficient in strength for good results. It yielded the weakest mortar tested, the strength of a 1:3 mixture at 90 days being only 140 lb. per sq. in., 38.1 per cent of that of the Ottawa standard sand mortar. This low strength is due both to the coating of clay on the sand grains and to the fineness and softness of the grains themselves. The tensile strength is so low that it would be advisable, and perhaps more economical, to abandon the use of this sand entirely. The specific gravity is 2.605, the weight per cu. ft. 101.0 lb., and the percentage of voids 37.9.

*Sample No. 28* (See Fig. 10).—This is a bar sand from the Wabash River near Mt. Carmel. It is yellowish in color and contains some flint, granite, and cinders. It is nearly as fine as sample No. 27 (see Fig. 4). It is the finest and also the dirtiest of the river sands, containing 2.4 per cent of suspended matter. The grains are well rounded. In common with the other fine sands, it forms a mortar of low strength, a 1:3 mixture showing a strength of only 170 lb. per sq. in. at 90 days, 46.2 per cent of that of the Ottawa standard sand mortar. The specific gravity is 2.635, the weight per cu. ft. 104.4 lb., and the percentage of voids 36.5. It ranks thirtieth in strength.

*Sample No. 29* (See Fig. 10).—This is a bank sand from along the Little Vermillion River above La Salle. It is gray in color and is composed almost entirely of quartz and the grains are well rounded. It is very fine, 99.3 per cent passing the No. 16 sieve and 26 per cent the No. 60 (see Fig. 4). There is 3.2 per cent of suspended matter present. The specific gravity is 2.65, the weight per cu. ft. 106.7 lb., and the percentage of voids 35.5. It ranks twenty-eighth in tensile strength, 1:3 mortar showing a strength at 90 days of 194 lb. per sq. in., 52.7 per cent of that of the Ottawa standard sand mortar.

*Sample No. 30* (See Fig. 11).—This sand is from the Crescent Gravel pit near Peoria. It is yellowish in color and contains some shale, flint, and granite. The grains are well rounded and quite fine, 90.3 per cent passing the No. 16 sieve and 17.8 per cent the No. 60 (see Fig. 4). It contains 2.7 per cent of suspended matter. The specific gravity is 2.665, the weight per cu. ft. 111.9 lb., and the percentage of voids 32.9. The tensile strength of 1:3 mortar at 90 days was 262 lb. per sq. in., 71.2 per cent of that of the Ottawa standard sand mortar. It ranks twenty-first in strength.



*Sample No. 31* (See Fig. 11).—This sand was taken from a large sewer trench near the center of the city of Peoria and was being used (1908) in the construction of the sewer. This sand is yellowish gray in color and contains some flint, granite, limestone, and chert. The medium-sized grains are more angular than either the coarser or the finer. It contains 1.9 per cent of suspended matter. It is quite fine, 86.5 per cent passing the No. 16 sieve (see Fig 4). This sand formed a stronger mortar than the other sands from the vicinity of Peoria. The tensile strength of 1:3 mortar at 90 days was 306 lb. per sq. in., 83.2 per cent of that of the Ottawa standard sand mortar. It ranks thirteenth in strength. The specific gravity is 2.64, the weight per cu. ft. is 103.9 lb., and the percentage of voids is 36.9.

*Sample No. 32* (See Fig. 11).—This is a bar sand from the Illinois River above Peoria. It is brownish gray in color and only about half of the grains are quartz, the remainder being flint, limestone, granite, chert, and cinders. The suspended matter amounts to 0.6 per cent. This sand is very fine (see Fig. 4), 97.1 per cent passing the No. 16 sieve. The specific gravity is 2.66, the weight per cu. ft. is 108.7 lb., and the percentage of voids is 34.6. The tensile strength of 1:3 mortar at 90 days was only 178 lb. per sq. in., 48.4 per cent of that of the Ottawa standard sand mortar. It ranks twenty-ninth in strength.

#### IV. DISCUSSION OF TESTS.

Although this series of tests includes only a small proportion of the different sands used in Illinois, it is believed that a sufficient number of samples, well distributed geographically, have been tested to serve as an index to the mortar-making qualities of the sands available in various sections of the State, and at the same time afford some information relative to the mortar-making qualities of sands in general. Following is a brief discussion of the results of this series of tests, together with the conclusions which may be drawn.

12. *Mineralogical Composition.*—The mineralogical composition of a sand is the fundamental factor in its mortar-making qualities, since not only its durability and hence the durability of the mortar but the size and gradation of the grains, the nature of the grain surfaces, the strength of the grains themselves, and all the other factors which affect the strength of the mortar are more or less directly dependent on the nature of the component materials of the sand.

The samples tested indicate that the majority of Illinois sands are

composed of satisfactory materials. Quartz is the principal component, forming the bulk of the medium-sized grains, and in most cases more than half of the entire volume of the sand. Limestone is the next in importance, while the other rocks form comparatively a small proportion of the whole.

13. *Specific Gravity*.—The specific gravity of a sand affords but little information relative to its mortar-making qualities, its principal value being as a factor in certain computations. Quartz has a specific gravity of about 2.65; and the nearer the specific gravity of a sand approaches this value the greater is the content of silicious material. A higher value indicates considerable quantities of materials other than quartz, which are likely to be hard and durable; while a lower value usually indicates the presence of soft, unsatisfactory material, or of considerable quantities of clay and loam or other foreign matter. The specific gravities of the samples tested ranged from 2.60 to 2.75.

14. *Sharpness*\*.—Angularity or irregularity of the sand grains appears to exert no effect on the tensile strength of the mortar. In compression, the sharp sands may show a slight advantage due to the interlocking of the angular grains; but evidently such action is insignificant as compared with the resistance to displacement of the grains afforded by the bond between them due to the adhesion of the cement to their surfaces, hence the strongest mortars are invariably those in which the cement most readily adheres to the sand grains. Crystalline rocks when freshly fractured generally show surfaces of great smoothness to which the cement does not adhere well; but when these grains have been worn down the surfaces become roughened and the cement adheres much more readily. This is particularly true of quartz as is evidenced by the fact that rounded silicious sands usually form mortars of greater strength than similar sharp sands. For example, note that sample No. 21 with its very sharp, glass-like grains gives only 70.2 per cent as much strength as the Ottawa standard sand with its spherical dull-surfaced grains, although the former is the better graded and the two are practically identical in composition and cleanness. With sands composed of rocks which naturally show a rough granular fracture this advantage of round grains is lost, but in any case mortars made of round-grained sands will compact more readily than those of sharp sands; hence such mortars in place are likely to be more compact and dense, which conduces to greater strength. The usual requirements of specifications that sands for mor-

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\*Sharpness is here used in its common meaning of angularity or irregularity in shape.



tar and concrete shall be sharp is not only useless but may even be detrimental and should therefore be omitted. Further, since the condition of the grain surfaces does materially affect the strength of the mortar, the specifications should fully cover this point.

15. *Voids*.—The percentage of voids in dry sand is a function of its compactness and the gradation of sizes in the sand grains, hence the effect of the voids on the strength of the mortar is included with that of the gradation of the sizes of the grains. The percentage of voids is valuable in determining the amount of cement necessary to give the densest mortar. The sands tested show voids varying from 28.5 to 39.4 per cent. The average sands contained 32 to 34 per cent when dry and well compacted.

16. *Size and Gradation of Grains*.—It has been demonstrated both by experiment and practice, that coarse sands will yield denser mortars than fine sands, and that the maximum density is obtained when the various sizes of grains are present in the proper proportions. Just what the proper proportions are, or in other words, what the ideal form of the sieve analysis curve is, has not as yet been determined. Experiments with materials for concrete indicate that for a mixture of cement, sand, and stone the sieve analysis curve should approximate a parabola, and by analogy it would seem that the same should be true of a mixture of cement and sand as well. Assuming that the parabola is the ideal line for the mixture, and remembering that the cement is very fine\*, it follows that the ideal line for the sand considered alone must lie *below* the parabola, and that it would be different for each proportion of cement used. But since the cement is very fine and forms a relatively large proportion in most mortars, the consequent variation in the ideal gradation for the sand considered alone will not be great; and hence it may be said that for the common proportions of cement and sand (1:1 to 1:4) the *flatter* the sieve analysis curve of the sand the denser will be the mortar made from it.

It has also been demonstrated that, other things being equal, the denser a mortar the greater is its strength; and hence the size and gradation of the grains is indirectly a factor in the strength of the mortar. Unfortunately, the fact that "other things must be equal" has been frequently overlooked with disappointing and sometimes disastrous results. It is only when the various sands are identical in mineralogical composition, condition of the grain surfaces, cleanness, etc., that the size and

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\*Standard specifications require that at least 92 per cent must pass the No. 100 sieve.

gradation of the grains becomes the controlling factor in the strength of the mortar, and even then it is only relative. Thus if two sands are exactly alike in all respects except size and gradation of the grains, the better graded sand will yield the mortar of both greater density and greater strength; but this strength may be decidedly less than that of a mortar from a third sand which may be less perfectly graded than either of the two given sands but is superior in other characteristics. Consequently we may have two sands which have identical sieve analyses and yield mortars of the same density, and yet these mortars may differ greatly in strength; or, two sands which differ greatly in their sieve analyses may form mortars of the same strength, although different in density. For example, note that samples Nos. 2 and 12 give mortars of practically the same strength, although their sieve analyses, as shown by Figs. 1 and 2, are decidedly different; while samples Nos. 13 and 32 are almost identical in sieve analysis (see Figs. 2 and 4), but their mortars show a wide difference in strength.

Where strength is of the first importance in a mortar the only criterion is a direct test for strength; but after the absolute strength of the mortar from any one sand is determined, the sieve analysis may indicate whether the strength can be somewhat increased by improving the gradation of the sand. In general this improvement must be accomplished by judicious screening rather than by the addition of other material, since usually the added material will not be of the same general character as the given sand. Where a dense or impervious mortar is required, the size and gradation of the grains is of more importance; and if strength is secondary, may control the choice of the sand. In this case the sieve analysis curves may be of considerable assistance in selecting the proper sand, or in indicating whether the desired results can be obtained either by combining several sands or by screening. In no case, however, should the direct test for strength be omitted, for a certain amount of strength is always required, and a good result for the sieve analysis is not sufficient evidence that the mortar will have sufficient strength.

The maximum size of grain permissible depends on the work for which the mortar is intended. For concrete the maximum size is now taken at  $\frac{1}{4}$  inch, but certain kinds of masonry, etc., require a much smaller maximum size. The maximum size of grain fixes the limits of sieve analysis, and consequently two sands may differ greatly in average fineness, and yet each one may be more perfectly graded and hence more suitable for some particular work than the other.

In general, the sands tested were quite fine and several of them



were extremely so. The bank sands showed the greatest difference in gradation. The river sands showed less difference in gradation than the bank sands, and although the latter also showed the greatest difference in strength, this is probably due more to a greater difference in the other characteristics than to a difference in gradation. In nearly every case there was a large amount of material caught between the No. 30 and the No. 60 sieves, and it is of interest to note that this material is nearly all silicious. It is also worthy of note that practically no quartz grains were retained on the No. 16 sieve. It is therefore to be expected that silicious sands will be comparatively fine and that the coarser sands will contain considerable quantities of less brittle rocks.

17. *Cleanness*.—Foreign material in a sand may affect the strength of the mortar by retarding or preventing the hardening of the cement, by preventing the adhesion of the cement to the sand grains, and if present in sufficient quantities by simple "dilution" of the cement. Organic matter is the most common source of trouble, but inert clay and loam may prove deleterious under certain conditions\*. Experiments indicate that finely divided inert clay or loam may be present in an average sand to the extent of 10 to 15 per cent without appreciably affecting the strength of the mortar, provided the clay or loam does not adhere to the grains, while a very small quantity may seriously impair the strength of the mortar if it forms a coating around the sand grains.

As would be expected, the river sands are the cleanest, showing an average of only 0.3 per cent. of suspended matter while the bank sands averaged 2.2 per cent even after omitting sample No. 18. This sand was the dirtiest one in the series. It contained 18.3 per cent of clay which adhered tightly to the grains and decreased the strength of the mortar both by its large quantity and by preventing a perfect bond between the cement and the sand grains. Sample No. 7 was the next dirtiest, containing 8 per cent of clay, but in contrast with No. 18 it did not coat the grains, and a test of the washed sand showed no increase in strength of the mortar over that of the unwashed sand, showing that even this amount of clay, when loose, had no appreciable effect on the strength of the mortar. In every case the suspended matter was inert clay or loam. It may be expected that in general Illinois sands will be free from injurious silts. It must not be forgotten, however, that appearances are deceiving and that a test is the only sure method of determining the quality of the sand or the effect of foreign matter.

\*For a very interesting discussion of the effect of organic silt on mortar, see Transactions of the American Society of Civil Engineers, Vol. 65, pp. 250-273.

18. *Tensile Strength.*—The tensile strength of the natural sand mortars varied from 140 to 464 lbs. per sq. in. at the age of 90 days. By comparing the tensile strengths with the sieve analysis curves, it will be seen that the coarser sands give the mortars of greater strength, and it will be noted that several of the sands show almost identical curves but that their tensile strengths are quite different, while still others giving practically the same strength differ greatly in their sieve analysis curves. An examination of the sands themselves shows that this variation is due to some of the other characteristics of the sands. Only five of the natural sands gave a tensile strength greater than the Ottawa standard sand; and it will be noted that all of these are bank sands with rounded grains, comparatively well graded and containing considerable material other than quartz. The river sands showed less variation in strength than the bank sands but this is to be expected since they differ less in composition, grading, and cleanness. It may, therefore, be expected that river sands will form mortars of only moderate strength, and that there is likely to be little variation between different sands; and that bank sands will furnish the mortars of greatest strength, but that the strength from different sands will vary through a wide range.

In an experimental investigation there is often a question as to how many individual results are necessary for the accurate determination of the result. It will be found that in any extended series of observed values of a single quantity one value is considerably less than the average, another considerably greater than the average, while the remaining values fill in the interval between these extremes more or less completely. If the values are platted as ordinates in the order of their magnitude with uniform horizontal spacing, the resulting curve will be found to have the form of an ogee or reversed curve, and the average value will lie at the point of reversal of the ogee. If the values are too few in number, the curve will be discontinuous, and the average value cannot be said to be accurately determined. As the number of values is increased the curve will become smoother and more complete; and it is only when the typical ogee form is distinctly and continuously outlined that the average value of the results can be considered as accurately determined.

Fig. 5 shows the results of the tensile tests of the mortars platted in the above manner, the ordinates being the strengths of the individual mortars in terms of the strength of standard Ottawa sand mortar. It will be observed that this figure shows the characteristic ogee curve quite distinctly, and therefore it may be considered that a sufficient number of



samples have been tested to yield a fairly representative average value of the strength which may be expected of mortars made from Illinois sands. This figure also shows graphically that the extreme values range from less than one-half of that of the standard Ottawa sand mortar to nearly one-third greater, and that the average value (at the point of reversal of the ogee) is about 80 per cent of the strength of the standard Ottawa sand mortar.

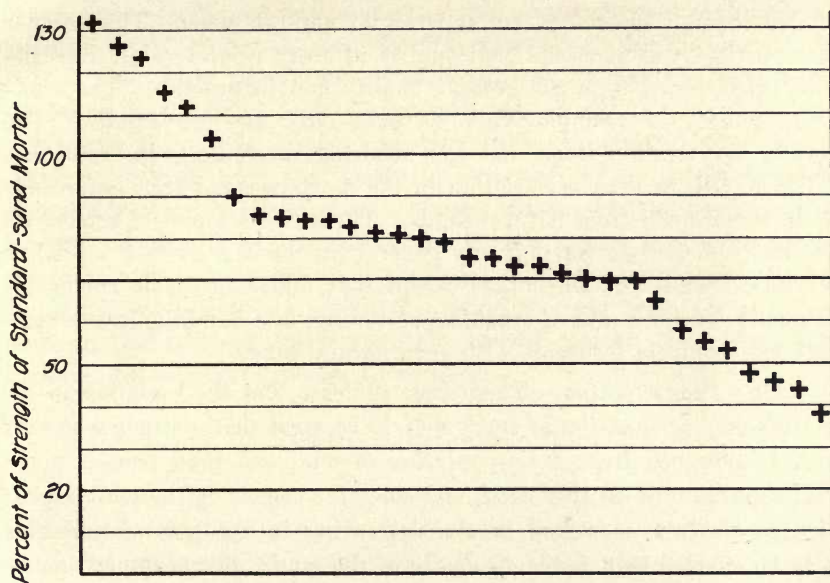


FIG. 5. STRENGTH OF BRIQUETTES MADE OF ILLINOIS SANDS IN TERMS OF THE STRENGTH OF STANDARD OTTAWA MORTAR.

It will be noted that in making these comparisons the tensile strength at 90 days is used. This age was chosen in that the results most nearly represent the ultimate strength of the mortars. A study of Table 1 will show that the mortars differ widely in the time required to attain approximately their maximum strength, and that the weak mortars invariably require less time than the strong mortars. This is explained by the fact that the strength of a mortar is largely dependent on the bond between the cement and sand. With poor sands the maximum bond is reached long before the cement has reached its full strength, while with the better sands the maximum bond is not attained until the cement has more completely hardened, and hence more time is required. Seven, fourteen, and possibly twenty-eight-day tests are there-

fore not absolutely reliable for comparing the ultimate strength of different sand mortars. For such comparisons the longest time available should be used. The short time tests are, however, of value in determining how soon it is permissible to remove forms or to subject the material to limited use.

19. *Crushed Stone Screenings.*—Although the limestone screenings (sample No. 4) formed the strongest mortar, it must not be concluded that all screenings are superior to natural sands. This sample of screenings was of exceptional quality in every respect, while the natural sands tested were the average quality met in practice. The sandstone screenings (sample No. 16) gave only medium results. The results for the limestone and the sandstone screenings indicate that there may be as great a variation in the mortars made from screenings as in those made from natural sands. These two samples of screenings are not sufficient to warrant any general conclusions as to the relative merits of sands and screenings except that under favorable conditions of quality of stone and of crushing, screening, and handling, the screenings may compete favorably with good natural sands.

20. *Proportioning.*—These tests indicate that the variation in the mortar-making qualities of sands may be so great that a stronger mortar may be obtained from a lean mixture of one sand than from a much richer mixture of another sand, and since the cement is the most expensive part of the mortar a substantial saving in the cost of materials may be effected by a judicious choice of the sand. For example, assume that a certain sand requires a 1:1 mixture by weight to give sufficient strength. If the cement cost \$1.50 per barrel and the sand \$0.40 per cu. yd., the materials for a cubic yard of mortar would be \$6.67.\* If the same strength could be secured with a 1:3 mixture of another sand which costs \$1.50 per cu. yd., the cost of the materials for a cubic yard of mortar would be only \$4.71. Thus a saving of \$1.96 per cubic yard of mortar could be effected by simply substituting a leaner mixture of a better sand although it is more expensive. It is thus seen that the *cost per unit of strength* of mortar can be materially reduced by a proper choice of materials. The same thing likewise applies to concrete, since the strength of the concrete is governed by the quality of the mortar entering into it and also by the quality of the aggregate. Thus a 1:3:6 mixture using one kind of sand and stone may form a stronger concrete than a 1:2:4 mixture using another kind of sand and stone and the same

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\*For data on the quantities required, see Baker's *Masonry Construction*, 10th ed., p. 120.



cement. If the unit cost of the material is the same and strength is the governing factor, it is evident that a considerable saving could be effected by using the leaner mixture of the better materials, and a higher price could often be paid for these materials and still yield a substantial saving.

The selection of the proper proportions for a mortar is essentially a problem in economics, whether the result to be attained is a mortar or concrete of maximum strength, or one of the greatest density and imperviousness, or simply one of sufficient strength for the purpose in hand. The object in any case is to obtain the desired result with the minimum cost. If this fact is kept in mind, it will become clear that it may really be true economy to spend what appears to be a considerable amount of time and money in investigating the available sands and determining the best combinations. Obviously, the saving to be effected varies with the magnitude of the work, and hence the bigger the job the more important it is that the materials be properly selected. If such investigations were generally made it would certainly result in reducing the careless and extravagant use of cement, the most costly material entering into mortar or concrete.

#### V. SPECIFICATIONS FOR SAND.

21. *Need for Definite Specifications.*—It is generally acknowledged that the specifications most frequently used for sand are inadequate in that they are too brief or too indefinite to secure the desired results. Recent specifications have overcome these defects in some respects, but most of them are objectionable in that they are too inflexible, *i. e.*, fail to allow variations in the quality of the sand to meet varying conditions or different requirements, or else by placing undue stress on some particular requirement bar from use sands which would prove entirely satisfactory. The following specifications have been prepared with the idea of giving this necessary flexibility, and at the same time of making them sufficiently rigid. It is not intended, however, that these specifications should be used indiscriminately for all purposes but rather that they should serve simply as a guide in preparing the specifications for any particular piece of work. In preparing these specifications both the specifications proposed by the national engineering societies and the results of the test described in this bulletin have been taken as guides.

22. *Definition of Sand and Screenings.*—The term *sand* shall be understood to mean natural sand which will pass, when dry, a screen

having  $\frac{1}{4}$  in. clear openings. Similar material which is the product of artificial crushing shall be known as *screenings*, and shall conform to the specifications for sand.

23. *Suggested Classification of Sands.*—Sands shall be classified as No. 1, No. 2, No. 3, plastering sand, and grout sand, the several grades being suitable for the following classes of work:

No. 1 sand is that required in reinforced concrete and in other work requiring a mortar of maximum strength and density.

No. 2 sand is that required in work not demanding maximum strength or density but still requiring a mortar of high quality.

No. 3 sand is that required where high strength or density are not controlling factors.

Plastering sand is that for use in ordinary plastering over masonry, concrete, and wood or metal lath. Either No. 3 sand or plastering sand is of high enough quality for use in lime mortars. The latter sand should be used where the thickness of the mortar joint is such as to require grains of small size.

Grout sand is that for use in pavement fillers and other work requiring a thin, smooth, free-running grout.

24. *Suggested Specifications for Sand.*—The author offers the following specifications for the various grades of sand according to the above classification. These specifications are based primarily upon the tests described in this bulletin, but it is hoped that they may be useful in preparing specifications for masonry work in general.

#### SPECIFICATIONS FOR NO. 1 SAND.

*Composition.*—No. 1 sand shall consist of grains from hard, tough, durable rocks, and be free from soft, decayed, or friable material.

*Cleanness.*—The sand must be free from lumps of clay, loam, or other foreign material. It shall not contain more than 2 per cent by weight of finely divided clay, loam, or other suspended matter when tested by washing in such a manner as to remove all such material without removing any of the finest sand; *provided*, that if the strength of the mortar made from the sand is greater than 110 per cent of the strength of a similar mortar made with standard Ottawa sand, the amount of suspended matter may reach 3 per cent. This suspended matter must not form a coating around the grains to such an extent that such coating is not entirely broken up and removed from the grains by sprinkling with water or in the mixing of the mortar or concrete. The sand shall



be free from oily or greasy matter in any form and must contain no organic silt.

*Roughness.*—The grains shall have rough, unpolished surfaces to which the cement paste will readily adhere.

*Size of Grains.*—The grains shall be well graded in size from the finest to the coarsest. For the greatest density not more than 8 per cent by weight, including the suspended matter, shall pass the No. 100 sieve, and not more than 60 per cent the No. 16 sieve. If maximum density is not essential and the mortar yields the required strength, these quantities may be increased to 12 per cent and 75 per cent, respectively.

*Voids.*—The voids in the dry sand, when well shaken, shall not exceed 33 per cent of the total volume of the sand.

*Tensile Strength.*—Mortar, in the proportions of 1:3 by weight, when tested at an age of 28 days shall develop a tensile strength at least equal to the strength of a similar mortar made of the same cement and standard Ottawa sand tested at the same age.

#### SPECIFICATIONS FOR NO. 2 SAND.

*General Requirements.*—No. 2 sand shall meet the requirements for No. 1 sand in all respects except as follows:

*Cleanness.*—The suspended matter shall not exceed 6 per cent by weight when tested in the same manner as described for No. 1 sand.

*Size of Grains.*—Not more than 15 per cent by weight, including the suspended matter, shall pass the No. 100 sieve, and not more than 80 per cent the No. 16 sieve.

*Voids.*—The voids shall not exceed 35 per cent of the total volume.

*Tensile Strength.*—The tensile strength shall equal at least 80 per cent of that of the standard Ottawa sand mortar when tested as described for No. 1 sand.

#### SPECIFICATIONS FOR NO. 3 SAND.

No. 3 sand shall meet the requirements of No. 2 sand, except that the suspended matter may reach 8 per cent and the tensile strength be as low as 65 per cent of that of the standard Ottawa sand mortar.

#### SPECIFICATIONS FOR PLASTERING SAND.

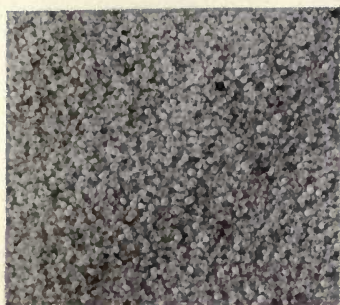
Plastering sand shall meet the requirements for No. 3 sand in all respects except that for the finishing coat it shall be of the requisite fineness to give the desired finish.

## SPECIFICATIONS FOR GROUT SAND.

Grout sand shall meet the requirements for No. 3 sand except as follows:

It shall all pass a No. 16 sieve. The voids shall not exceed 38 per cent of the total volume. The tensile strength shall be at least 40 per cent of that of the standard Ottawa sand mortar.





Sample No. 0



Sample No. 1



Sample No. 2



Sample No. 3

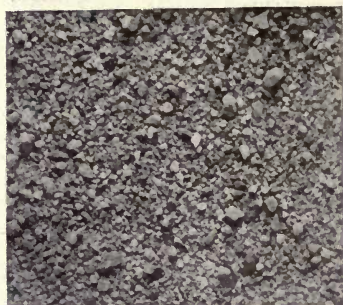


Sample No. 4



Sample No. 5

FIG. 6. PHOTOGRAPHS OF SAMPLES NO. 0 TO 5.



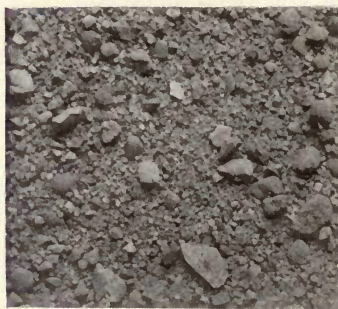
Sample No.6



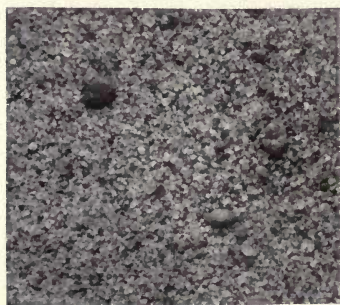
Sample No.7



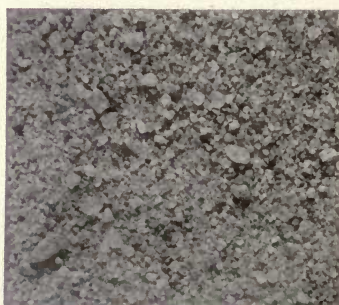
Sample No.8



Sample No.9



Sample No.10



Sample No.11

FIG. 7. PHOTOGRAPHS OF SAMPLES NO. 6 TO 11.



11  
12  
13  
14  
15  
16  
17



Sample No. 12



Sample No. 13



Sample No. 14



Sample No. 15



Sample No. 16

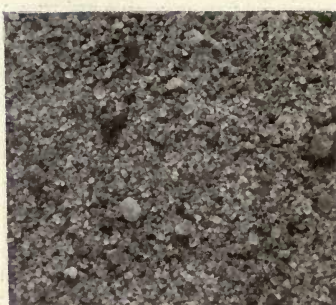


Sample No. 17

FIG. 8. PHOTOGRAPHS OF SAMPLES NO. 12 TO 17.



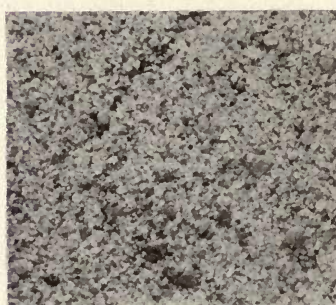
Sample No. 18



Sample No. 19



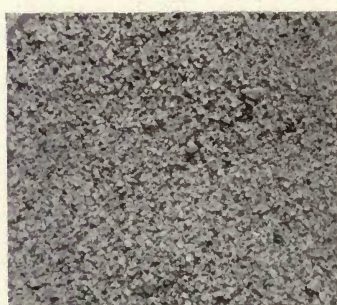
Sample No. 20



Sample No. 21



Sample No. 22



Sample No. 23

FIG. 9. PHOTOGRAPHS OF SAMPLES NO. 18 TO 23.

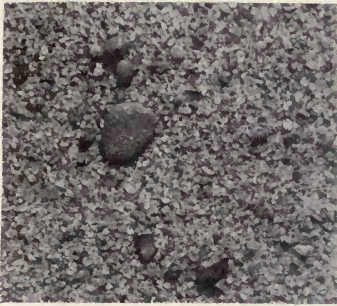




Sample No. 24



Sample No. 25



Sample No. 26



Sample No. 27



Sample No. 28



Sample No. 29

FIG. 10. PHOTOGRAPHS OF SAMPLES No. 24 TO 29.



Sample No. 30



Sample No. 31



Sample No. 32

FIG. 11. PHOTOGRAPHS OF SAMPLES No. 30 TO 32.



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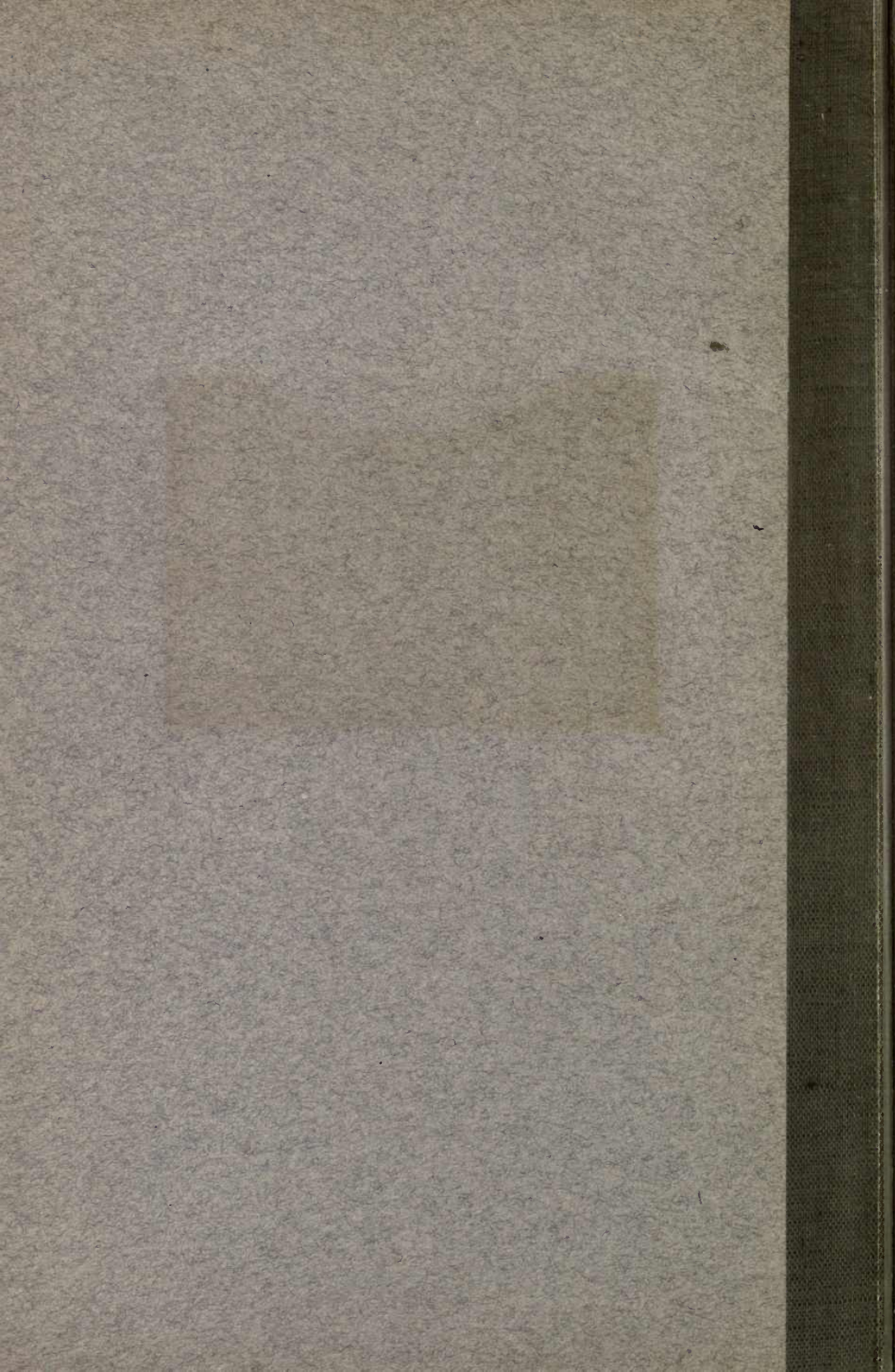
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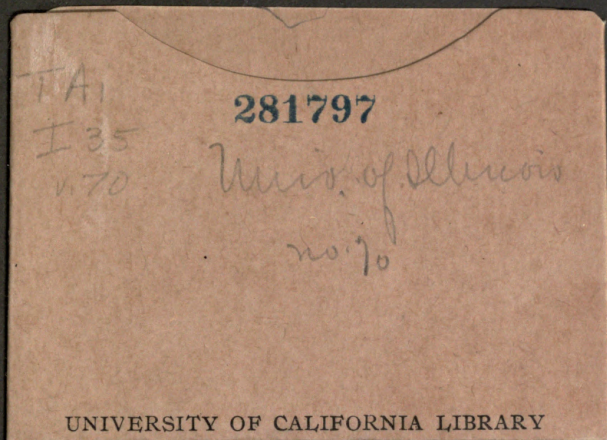
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